JOURNAL
of
STEEL CASTINGS RESEARCH

CONTENTS

The Effect of Calcium Alloy Ladle Additions on Aluminum Killed Mild Steel 1

A Statistical Analysis of Calcium Deoxidation Data . . . 7

Magnetic Properties of Cast Carbon Steels 10

Abstracts of Fundamental Papers on Steel Casting Research . 15

STEEL FOUNDERS' SOCIETY OF AMERICA

NUMBER 20 JANUARY, 1961

JOURNAL OF STEEL CASTINGS RESEARCH

Number 20 January, 1961

TECHNICAL RESEARCH COMMITTEE, SFSA

V. E. ZANG, Unitcast Corporation, Chairman

R. D. AHLES, General Electric Company

F. H. ALLISON, JR., Foundry & Mill Machinery Division, Blaw Knox Company

H. H. BLOSJO, Malleable Iron Fittings Company

W. K. BOCK, National Malleable & Steel Castings Company

A. P. GUIDI, Texas Foundries, Inc.

G. F. HAISLUP, Electric Steel Castings Company

CHARLES LOCKE, Crucible Steel Casting Company

PHILIP McCAFFERY, General Metals Corporation

C. E. STULL, The Pelton Steel Casting Company

E. A. WALCHER, JR., American Steel Foundries

W. D. WALTHER, The Dayton Steel Foundry Company

DIRECTOR OF RESEARCH AND JOURNAL EDITOR
CHARLES W. BRIGGS

EDITORIAL STAFF

R. A. WILLEY,
Assistant Technical
and Research Director

CHARLES A. ROWE,
Assistant to the Technical
and Research Director

© by Steel Founders' Society of America, 1961

606 Terminal Tower Cleveland 13, Ohio

THE CIRCULATION OF THE JOURNAL IS RESTRICTED TO MEMBERS OF THE SOCIETY AND OTHERS AS AUTHORIZED BY THE BOARD OF DIRECTORS

THE EFFECT OF CALCIUM ALLOY LADLE ADDITIONS ON ALUMINUM KILLED MILD STEEL

by

G. L. Montgomery*

The following report is the result of research sponsored by the Steel Castings Institute of Canada and Steel Founders' Society of America.

ABSTRACT

Results of a series of acid and basic electric steel heats of .25 percent carbon steel and one of .30 to .40 percent carbon steel, treated with aluminum, aluminum plus CaSi, aluminum plus Ca-Mn-Si and aluminum plus graphidox are presented, with particular emphasis given to the variations in tensile ductility and impact properties afforded by the addition of the calcium deoxidizers. Variations in the type of inclusion obtained, as a result of using chill molds, are noted and explained in the light of theories having to do with various modes of solidification. A description is also given of two heats devised to determine the effect of the travel of molten steel on the analysis of the steel and the inclusion distribution obtained.

INTRODUCTION

Calcium alloys have been extensively employed by the steel castings industry for the maintenance of high ductility in the acid and basic electric processes. Calcium silicide and calcium-manganese-silicon are widely used as ladle additions to aid in the deoxidation of steel.

It is the opinion of a number of investigators that calcium silicide and calcium-manganese-silicon are effective deoxidizing agents and tend to reduce the distribution or quantity of harmful non-metallic inclusions in the steel.[1,2,3] Calcium has a high affinity for oxygen and from a thermodynamic viewpoint, it would appear that the oxygen content of the steel might be reduced to extremely low values by the addition of this element. However, the efficacy of calcium alloys as addition agents in steel has been rejected a number of times,[4,5,6] principally and most recently in the Steel Founders' Society of America Research Report No. 39, "A Study of Deoxidation and Desulfurization of Cast Steels".[7] Herein it was concluded that "calcium additions ordinarily have no significant effect on either the mechanical properties or the inclusion characteristics of cast steels. Calcium additions may actually increase the oxygen content and decrease the carbon and aluminum contents of liquid steel because they produce violent agitation resulting in oxidation by air."

*Research Engineer, Steel Castings Institute of Canada, Department of Mines and Technical Surveys, Ottawa, Ontario, Canada.

The conclusions of Research Report No. 39 were based largely on a study of inclusion characteristics. The heats were made in an induction furnace and it was agreed that the results given might be checked under conditions more closely approximating industrial practice. It was proposed to undertake an investigation of calcium alloy additions on commercially made steels in direct arc furnaces. The project was designed to be an accurate and controlled study of an industrial process.

SECTION A

A Comparison of the Effectiveness of Some Widely Used Ladle Additions in Mild Steel

Experimental Procedure

The heats were made at two of the member foundries in Montreal, the acid heats at Canadian Steel Foundries and the basic heats at Dominion Engineering Works. The steel made was of the following composition:

Carbon	-	0.20 - 0.30 aim 0.25
Manganese	-	0.60 - 0.80
Silicon	-	0.40 - 0.60
Sulfur	-	.030 max. for basic, .060 max. for acid
Phosphorus	-	.030 max. for basic, .050 max. for acid

The two foundries have each carried out 18 heats as follows:

5 heats with Al ladle deoxidation
5 heats with Al plus CaSi ladle deoxidation
5 heats with Al plus Ca-Mn-Si ladle deoxidation
3 heats with Al plus graphidox

Amounts of the ladle additions were as given below:

	Acid	Basic
Al	2½ lb/ton	2 lb/ton
CaSi	2½ lb/ton	3 lb/ton
Ca-Mn-Si	2½ lb/ton	4 lb/ton
Graphidox	3 lb/ton	3 lb/ton

From the product of each heat, two standard SFSA 4-legged keel blocks in dry sand and two in cast iron molds were poured. The final product was analyzed for carbon, silicon, manganese, sulfur, phosphorus, oxygen and aluminum. The legs were cut from the keel blocks and were heat treated for 20 minutes at 1650 degrees F and cooled in still air. In order to eliminate as many of the variables as possible, the bars were placed for cooling from the austenitizing

temperature across two thin-walled pipes at intervals of 3 inches.

Three tensile bars and eight Charpy "V" notch bars were machined from both the sand cast and chill cast legs. Machining was done at the producing foundries with the exception of the notching of the Charpy bars which was done by the Technical Services Division of the Department of Mines and Technical Surveys at Ottawa.

Two Charpy bars were broken at 70 degrees F, three at 32 degrees F and two at -40 degrees F. The testing of Charpy bars was done at the Physical Metallurgy Division in Ottawa. Tensile bars were pulled in the mechanical laboratory at Dominion Engineering. Two samples were extracted from each tensile bar (for metallographic examination) one from the center and one from the section adjacent to the mold interface.

Results

Results of mechanical testing are presented graphically in Figures 1 through 6. Metallographic examination revealed the predominant inclusion types to be as shown in Tables I and II.

It was observed that the harmful eutectic type inclusions appeared regularly where the grain structure was equiaxed, as in the chill cast blocks. A further observation was that, in almost every sample examined, type II inclusions were observed in the region adjacent to the mold interface. This was found to be the case in sand as well as chill cast samples regardless of the ladle additions used and irrespective of the predominant inclusion type in the center of the casting. It is significant to note that this is a region of equiaxed grain structure. This will be discussed further in the Appendix.

TABLE I—Predominant Inclusion Type Found in Acid Steels

Ladle Addition	Predominant Inclusion Type Sand Cast	Chill Cast
Al	I or III	II
Al, CaSi	III	II
Al, Ca-Mn-Si	III	II
Al, Graphidox	III	II

TABLE II—Predominant Inclusion Type Found in Basic Steels

Ladle Addition	Predominant Inclusion Type Sand Cast	Chill Cast
Al	I or III	II
Al, CaSi	III	II
Al, Ca-Mn-Si	III	III
Al, Graphidox	III	II

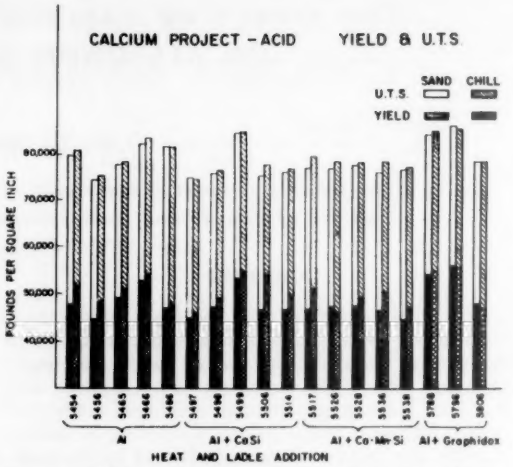

Figure 1—Yield and ultimate tensile strength versus deoxidation practice for acid steel in both sand and chill molds.

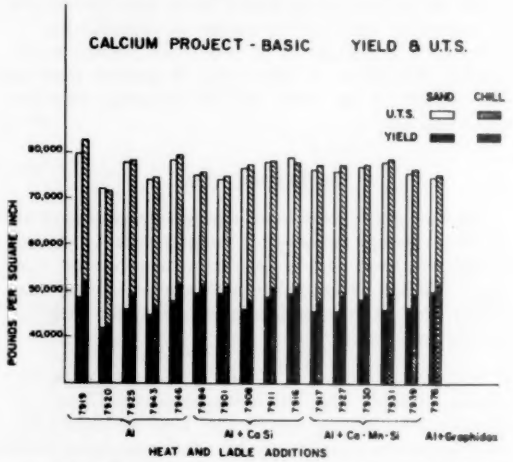

Figure 2—Yield and ultimate tensile strength versus deoxidation practice for basic steel in both sand and chill molds.

SECTION B

Double Keel Block Experiments

Experimental Procedure

Two heats of Al killed acid steel, one with and one without CaSi ladle addition, were cast at Canadian Steel Foundries in Montreal. The construction of the mold was as shown in Figure 7.

Two dry sand four-legged keel molds were anchored in the drag and separated by a distance of three feet. They were connected in the mold by a runner cut from the sand so that one of the blocks could be run through the other. The sprue fed directly into one of the molds. Heat treating, mechanical and metallographic testing were carried out as described in Section A.

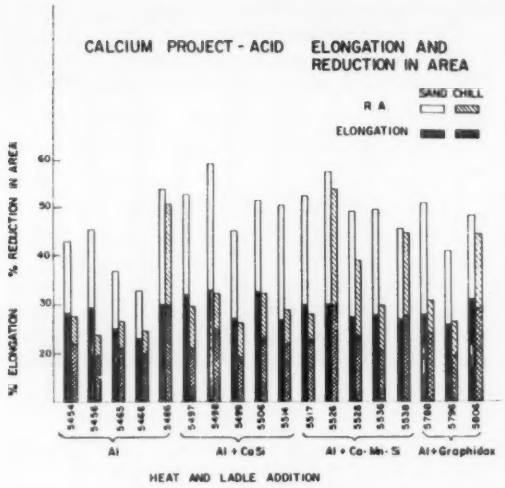

Figure 3—Elongation and reduction in area versus deoxidation practice for acid steel in both sand and chill molds.

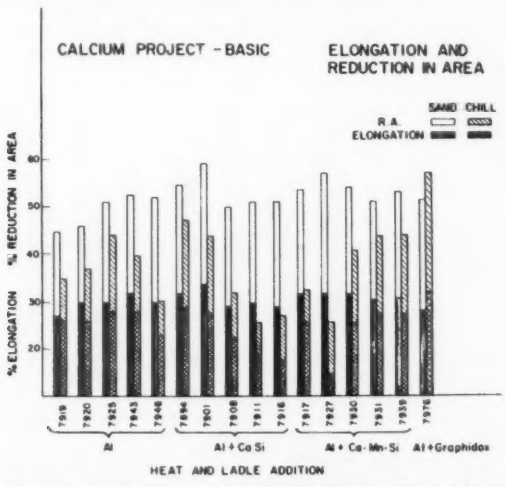

Figure 4—Elongation and reduction in area versus deoxidation practice for basic steel in both sand and chill molds.

Results

The results of mechanical testing are shown graphically in Figure 8. A marked similarity is seen between the mechanical test results from the entrance and the "long travel" blocks,, indicating that the effect of travel is not particularly severe, at least under the conditions and for the steel used.

Micrographs showed the preferable inclusion arrangement in each case to be in the entrance block. CaSi seems definitely to improve the distribution of inclusions. Only the long travel block not treated with CaSi has an appreciable number of eutectic type II inclusions. Analysis shows that little, if any, aluminum is lost to the long travel block. The different inclusion arrangement in entrance and long travel

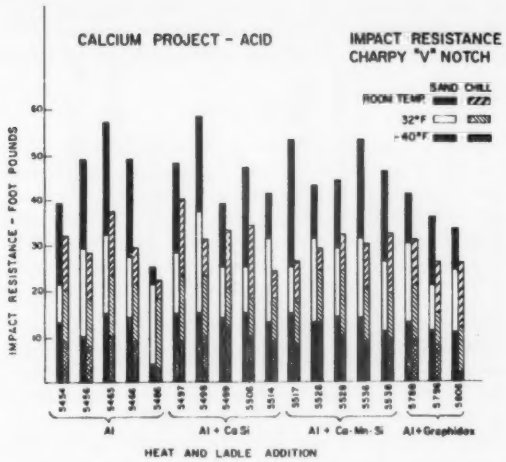

Figure 5—Charpy V-Notch impact resistance versus deoxidation practice for acid steel in both sand and chill molds.

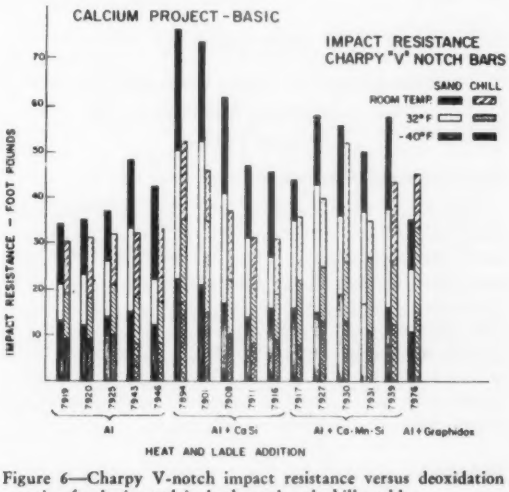

Figure 6—Charpy V-notch impact resistance versus deoxidation practice for basic steel in both sand and chill molds.

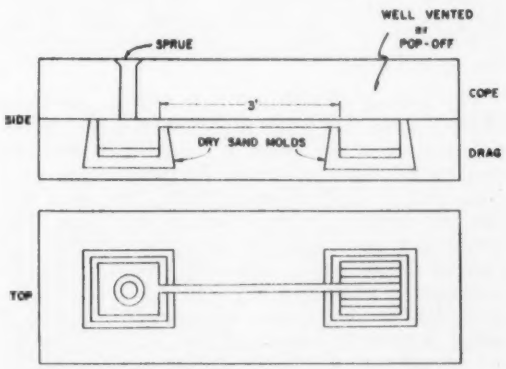

Figure 7—Mold construction for double keel block tests.

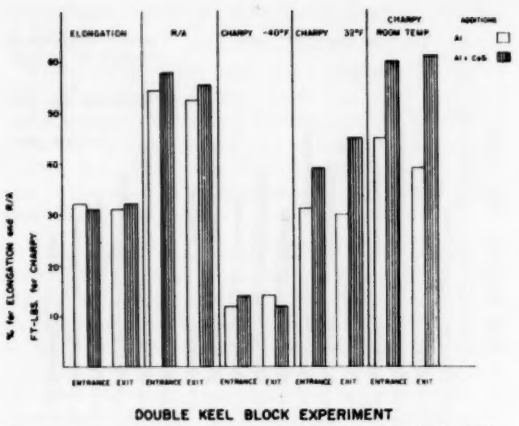

Figure 8—Results of mechanical testing of double keel blocks.

test blocks is, therefore, likely due to added heat loss (and therefore different solidification conditions) in the latter.

SECTION C

Effect of Calcium Alloy Deoxidizers on Steel Containing from .30 to .40 Percent Carbon

Experimental Procedure

The heats were made at the Physical Metallurgy Division, Mines Branch, Ottawa, in a 500-pound basic electric furnace. Each of the heats was split into three ladles and to each was added 3 lbs/ton of aluminum during tapping. In addition, 3 lbs/ton of CaSi was added to ladle No. 1 and 3 lbs/ton of Ca-Mn-Si was added to ladle No. 2. One keel block in dry sand and one in a cast iron mold were poured from each ladle. Further treatment and experimentation were as described in Section A.

Results

Results obtained are shown graphically in Figures 9 through 11. Metallographic examination revealed the predominance of type II sulfides, except in the case of heat 1308 chill cast samples, which exhibited type II inclusions.

The content of retained aluminum in the heats of this section was rather high and, as might be expected, a few of the tensile bars made from sand cast coupons exhibited rock-candy fractures. These were Nos. 1290-3S, 1289-1S and 1289-2S. The result was that the ductility of these samples was poor. The tensile bars made from the corresponding chill cast coupons did not show rock-candy fractures. Aluminum nitride, which is stated to be the cause of rock-candy fracture, precipitates at about 2910 degrees F and it is generally considered that, in chill castings, not enough time is available during solidification for their formation.

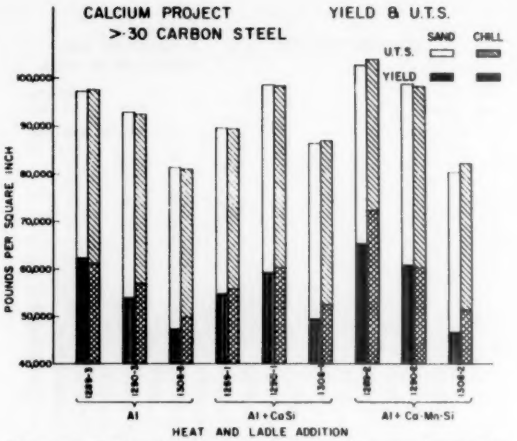

Figure 9—Yield and ultimate tensile strength versus deoxidation practice for .30 to .40 percent carbon cast steel.

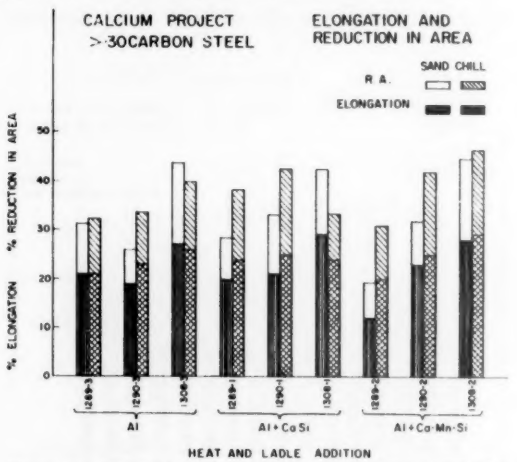

Figure 10—Elongation and reduction in area versus deoxidation practice for .30 to .40 percent carbon cast steel.

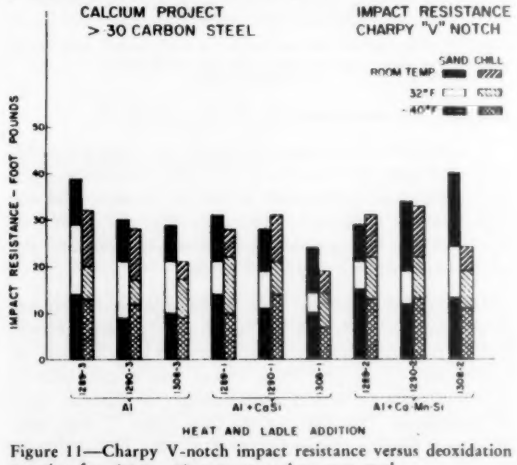

Figure 11—Charpy V-notch impact resistance versus deoxidation practice for .30 to .40 percent carbon cast steel.

Once again, there appears to be a slight improvement in ductility obtained by additions of CaSi and Ca-Mn-Si. There is little, if any, improvement of impact properties as a result of these additions.

Sulfur analyses showed that CaSi and Ca-Mn-Si are totally ineffective in removal of sulfur.

GENERAL CONCLUSIONS

This project was intended to test the conclusions of SFSA Research Report No. 39 regarding calcium alloy ladle additions on commercial steel heats. The results obtained during the present work neither agree totally, nor irrevocably dispute the conclusions reached in that report. They show that:

1. The addition of CaSi or Ca-Mn-Si in conjunction with aluminum, tends under certain conditions, to somewhat improve the tensile ductility and, to a lesser extent, the impact properties of both acid and basic steel.

2. A fairly substantial improvement in impact properties, by additions of CaSi and Ca-Mn-Si to basic steel, was noted. This was not true for acid steel.

3. CaSi additions seem to have little effect on either acid or basic electric steels cast in chill molds. Ca-Mn-Si, on the other hand, effected a slight improvement in the ductility of chill cast basic steel and a decided improvement in that of chill cast acid steel.

4. The deoxidizer Graphidox, which has the analysis

Silicon	-	48 to 52 percent
Titanium	-	9 to 11 percent
Calcium	-	5 to 7 percent

as given by the manufacturer, was ineffective in improving the tensile ductility and impact properties of mild steel.

5. It has been suggested that calcium alloy additions are more helpful to higher carbon steels (.30 to .40 percent carbon) where the problem of maintaining ductility and impact properties is greater. However, it would appear that these alloys are not as effective when used with the higher carbon steels.

6. The observations and results of this report indicate that calcium alloy ladle additions should not be used as widely as at present. The benefits achieved by their use are not great and are only helpful in borderline cases. For example, a foundry might be having difficulty maintaining ductility to meet a specification. Providing that the ductility is not seriously low (which would indicate that pronounced changes to the practice were necessary), the addition to the ladle of CaSi or Ca-Mn-Si along with aluminum would likely produce an improvement sufficient to insure the regular meeting of specification requirements. However, the everyday use of calcium alloy ladle additions would seem to be inadvisable and unnecessary.

APPENDIX

Of particular interest is the observation that a rapid withdrawal of heat (as in the chill cast coupons) gives rise to intergranular eutectic inclusions and poor ductility. There is much to indicate that the eutectic sulfides tend to zones of equiaxed crystals, whereas the peretectic, type III inclusions are found in areas where the grains are columnar.

As solidification proceeds toward the center of the casting, solute atoms are rejected at the solid-liquid interface. Since the rate of solute diffusion is, under ordinary circumstances, smaller than the rate of advance of the interface, there results a build-up of solute concentration ahead of the interface (Figure 12a). At each point ahead of the interface, the melt will have a certain liquidus temperature as determined by the solute concentration and predicted by the phase diagram (Figure 12b).

A temperature gradient exists ahead of the interface, the slope of which will depend on the severity of heat transfer. Since this gradient tends to linearity, whereas the concentration build-up is exponential, there will be a region ahead of the interface which will exist as a liquid at a temperature below its liquidus (shaded portion, Figure 12a). This gives rise to the condition described by Tiller et al[9] as "constitutional super-cooling," and results in directional or columnar solidification.

Upon reaching the saturation point as a result of the concentration build-up, the sulfides precipitate and gradually become entrapped between dendrites as the interface advances. Precipitation of sulfides under such conditions takes place at a point during solidification where size and shape are determined by their own morphology.

If heat is withdrawn more rapidly, the supercooled zone will penetrate further into the melt. If the chilling is sufficient, crystals will nucleate in the liquid ahead of the interface and halt the growth of dendrites. This results in the so-called "mushy zone" mode of solidification (see Figure 13).

Tiller[10] postulates that these grains nucleate and grow radially at a velocity dependent on the degree of supercooling.

In this case there is not enough time for a build-up of solute concentration sufficient to produce solute saturation and precipitation at the interface of the grains before they grow together. The additions of deoxidizers eliminate those oxides whose presence lower the solute (sulfide) solubility. Consequently the sulfide compounds, which form inclusions are precipitated as a eutectic late in the solidification process.

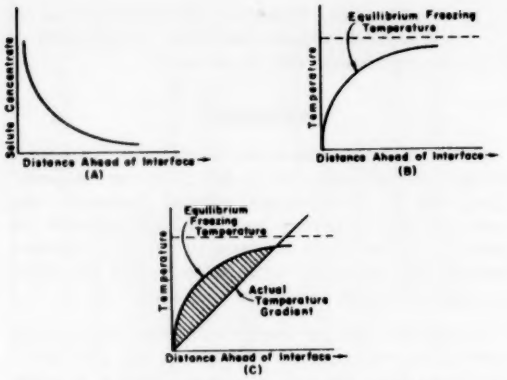

Figure 12—Interface phenomena during solidification.

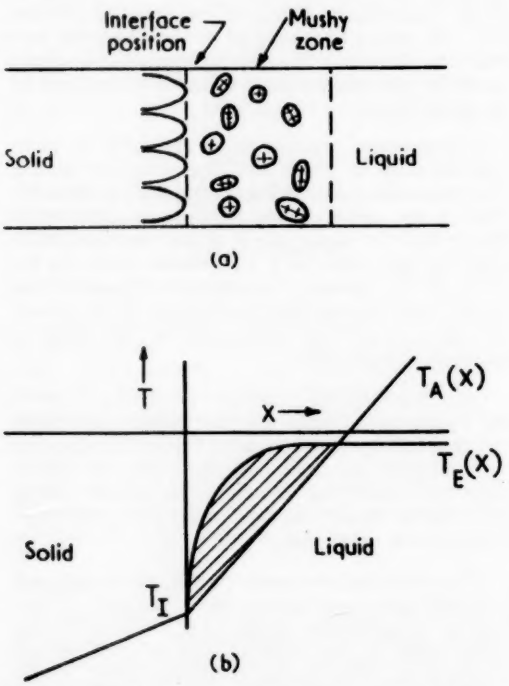

Figure 13—Mushy zone mode of solidification as related to temperature gradients. (from Tiller)[10]

TABLE III—Results of Chemical and Metallographic Analyses of Different Section Thicknesses

Section Thickness	Oxygen	Aluminum	Inclusion Type
1"	.008%	.09%	III
.2"	.009%	.08%	II
.05"	.014%	.10%	II extremely predominant

The result of this is that these compounds are positioned in the only space available to them—the grain boundaries—as long continuous or semi-continuous films. Tiller suggests that inclusions of this type are largely FeS and he attests that this grain boundary film may be eliminated by the addition to the melt of an appropriate element which will produce a more stable sulfide than FeS. He observes that manganese is the most effective element.

It appears, therefore, that the effect of varying the rate of heat transfer is identical with that of an effective change in sulfide solubility; that is, precipitation takes place sooner—giving peritectic inclusions, or later—giving eutectic inclusions—in the solidification of the melt.

To test this hypothesis, three samples of varying section thickness were taken from the same casting, examined metallographically and analyzed for oxygen and aluminum. The results are given in Table III.

Type II inclusions were apparent in the thinner section—intensely so in the extremely thin one, where the heat will have been withdrawn more rapidly because of the higher surface area to volume ratio.

The higher oxygen content of the .05-inch section is attributed to the oxidized surface layer of this section being a much larger portion of the total volume of the sample and is not considered to have contributed in any measure to the predominance of eutectic type inclusions.

REFERENCES

1. Gagnebin - "Effect of Deoxidation Treatments on the Ductility of Cast Steels" - Trans. A.F.A. 46, 133-155 (1938).

2. Wyman - "Effect of Various Types of Final Deoxidizers on Physical Properties of Class B Steel" - Electric Furnace Steel Proc. AIME 8, 159-174 (1950).

3. Crafts, Egan, Forgeng - "Formation of Inclusions in Steel Castings" - Trans. Iron and Steel Div. AIME 140, 233-250 (1940).

4. Kroll - Discussion - Trans. Electrochemical Soc. 46, 81-83 (1934).

5. Sims and Dahle - "Effect of Aluminum on the Properties of Medium Carbon Cast Steel" - Trans. A.F.A. 46, 65-104 (1938).

6. Sims, Saller, Boulger - "Effects of Various Deoxidiers on the Structure of Sulphide Inclusions" - Trans. A.F.S. 51, 233-247 (1949).

7. Boulger and Sims - "A Study of Deoxidation and Desulphurization of Cast Steel" - SFSA Research Report No. 39 (1957).

8. Sims and Lillieqvist - "Inclusions - Their Effect, Solubility and Control in Cast Steel" - Trans. AIME 100, 154-175 (1932).

9. Tiller, Jackson, Rutter and Chalmers - "The Redistribution of Solute Atoms During the Solidification of Metals" - Acta Met. 1, 428-437 (1953).

10. Tiller - "Solute Segregation During Ingot Solidification" - J. Iron and Steel Inst. 192, 388-350 (1959).

ACKNOWLEDGMENTS

The writer wishes to thank the personnel at Dominion Engineering Works Limited, Montreal, and Canadian Steel Foundries (1956) Limited, Montreal, for so ably carrying out those sections of the work done in their foundries.

The writer would also like to acknowledge the invaluable assistance of Mr. S. L. Gertsman and his staff at the Physical Metallurgy Division, Mines Branch, Ottawa. Their cooperation is greatly appreciated.

A STATISTICAL ANALYSIS OF CALCIUM DEOXIDATION DATA

by

C. A. Rowe*

The following is a statistical analysis of data presented in the preceding paper.

Reason for Using Statistical Techniques

The prime reason for using statistical techniques in the evaluation of experimental data is to give the experimenter a knowledge of the chance variation which can occur in the measurement of the same or of different properties. Armed with this knowledge, the experimenter will then be able to discern between different samples to determine if they are truly measurements of separate quantities or merely measurements of the same quantity.

The cautious investigator will try to eliminate bias by considering the possibility of the apparent difference between two samples being due to pure chance. Suppose he were asking whether a new process he had tried were better than the existing process. He might then adopt what the statistician calls a *Null Hypothesis,* i.e., he would assume that there was no significant difference between the new process and the standard process. His next step would be to calculate the probability that the new process had produced a sample which was better than the sample produced by the standard process. If the probability that there is a true difference between the samples is sufficiently great, then the Null Hypothesis can be rejected and it can be concluded that a real difference exists between processes.

The Variance Ratio Test

The test which will be used here to determine if a significant difference exists between steels killed with aluminum only and those killed with aluminum plus calcium will be the Variance Ratio Test. This test will enable the investigator to determine whether a significant difference between two or more samples really exists, or is likely to be due to chance.

* Assistant to the Technical and Research Director, Steel Founders' Society of America, Cleveland, Ohio.

The Variance Ratio Test is often referred to as the "F" test and depends mathematically on an extremely general and fundamental distribution. No attempt will be made here to explain the mathematics of this test nor to explain all the writer's calculations which enabled him to arrive at the figures shown in the next section. This is somewhat involved and is beyond the scope of this report.

Presentation of Data

The properties which are investigated in this analysis are the ductility and impact properties of the sand cast keel blocks. The chill cast keel blocks are not discussed since the practical foundryman's interest in these properties is secondary to interest in the sand cast keel blocks.

The Variance Ratio Tests produced the following information:

1. Acid Steel - Sand Cast

a) Elongation -

Deoxidation Practice	Average Value	Number in Sample
Al only	27.0%	5
Al + CaSi	29.8%	5
Al + CaMnSi	29.0%	5
Al + Graphidox	28.3%	3

Variance between samples=6.67, with 3 degrees of freedom

Variance within samples=6.15, with 14 degrees of freedom

$$F = \frac{6.67}{6.15} = 1.08 \frac{(3)}{(14)}$$

Therefore no significant difference exists between samples.

b) Reduction of Area -

Deoxidation Practice	Average Value	Number in Sample
Al Only	42.4%	5
Al + CaSi	51.8%	5
Al + CaMnSi	51.2%	5
Al + Graphidox	47.3%	3

Variance between samples=92.7, with 3 degrees of freedom

Variance within samples=35.3, with 14 degrees of freedom

$$F = \frac{92.7}{35.3} = 2.62 \frac{(3)}{(14)}$$

Therefore no significant difference exists between samples.

c) V-Notch Impact at −40°F -

Deoxidation Practice	Average Value	Number in Sample
Al only	11.2 ft-lbs.	5
Al + CaSi	14.4 ft-lbs.	5
Al + CaMnSi	13.4 ft-lbs.	5
Al + Graphidox	11.7 ft-lbs.	3

Variance between samples=10.3, with 3 degrees of freedom

Variance within samples=6.15, with 14 degrees of freedom

$$F = \frac{10.3}{6.15} = 1.68 \frac{(3)}{(14)}$$

Therefore no significant difference exists between samples.

d) V-Notch Impact at 32°F -

Deoxidation Practice	Average Value	Number in Sample
Al only	26.0 ft-lbs.	5
Al + CaSi	29.2 ft-lbs.	5
Al + CaMnSi	28.4 ft-lbs.	5
Al + Graphidox	25.0 ft-lbs.	3

Variance between samples=16.0, with 3 degrees of freedom

Variance within samples=19.3, with 14 degrees of freedom

$$F = \frac{19.3}{16.0} = 1.2 \frac{(14)}{(3)}$$

Therefore no significant difference exists between samples.

e) V-Notch Impact at 70°F -

Deoxidation Practice	Average Value	Number in Sample
Al only	43.8 ft-lbs.	5
Al + CaSi	46.6 ft-lbs.	5
Al + CaMnSi	47.8 ft-lbs.	5
Al + Graphidox	36.7 ft-lbs.	3

Variance between samples=87.3, with 3 degrees of freedom

Variance within samples=68.1, with 14 degrees of freedom

$$F = \frac{87.3}{68.1} = 1.28 \frac{(3)}{(14)}$$

Therefore no significant difference exists between samples.

2. Basic Steel - Sand Cast

a) Elongation -

Deoxidation Practice	Average Value	Number in Sample
Al only	29.8%	5
Al + CaSi	30.8%	5
Al + CaMnSi	31.6%	5
Al + Graphidox	28.0%	1

Variance between samples=5.0, with 3 degrees of freedom

Variance within samples=2.74, with 12 degrees of freedom

$$F = \frac{5.0}{2.74} = 1.83 \frac{(3)}{(12)}$$

Therefore no significant difference exists between samples.

b) Reduction of Area -

Deoxidation Practice	Average Value	Number in Sample
Al only	49.4%	5
Al + CaSi	53.2%	5
Al + CaMnSi	54.2%	5
Al + Graphidox	52.0%	1

Variance between samples=21.4, with 3 degrees of freedom

Variance within samples=10.2, with 12 degrees of freedom

$$F = \frac{21.4}{10.2} = 2.1 \frac{(3)}{(12)}$$

Therefore no significant difference exists between samples.

c) V-Notch Impact at −40°F -

Deoxidation Practice	Average Value	Number in Sample
Al only	13.2 ft-lbs.	5
Al + CaSi	18.0 ft-lbs.	5
Al + CaMnSi	16.6 ft-lbs.	5
Al + Graphidox	11.0 ft-lbs.	1

Variance between samples=27.7, with 3 degrees of freedom

Variance within samples=5.25, with 12 degrees of freedom

$$F = \frac{27.7}{5.25} = 5.3 \frac{(3)}{(12)}$$

Therefore a significant difference DOES exist between samples. The difference between samples is significant at the 5% level.

d) V-Notch at 32°F -

Deoxidation Practice	Average Value	Number in Sample
Al only	25.0 ft-lbs.	5
Al + CaSi	40.2 ft-lbs.	5
Al + CaMnSi	37.6 ft-lbs.	5
Al + Graphidox	24.0 ft-lbs.	1

Variance between samples = 253.3, with 3 degrees of freedom

Variance within samples = 52.3, with 12 degrees of freedom

$$F = \frac{253.3}{52.3} = 4.84 \frac{(3)}{(12)}$$

Therefore a significant difference DOES exist between samples. The difference between samples is significant at the 5% level.

e) V-Notch Impact at 70°F -

Deoxidation Practice	Average Value	Number in Sample
Al only	39.2 ft-lbs.	5
Al + CaSi	60.8 ft-lbs.	5
Al + CaMnSi	53.0 ft-lbs.	5
Al + Graphidox	35.0 ft-lbs.	1

Variance between samples = 479, with 3 degrees of freedom

Variance within samples = 89, with 12 degrees of freedom

$$F = \frac{479}{89} = 5.39 \frac{(3)}{(12)}$$

Therefore a significant difference DOES exist between samples. The difference between samples is significant at the 5% level.

Discussion of Data

The data presented above are only a summary of the calculations used in applying the Variance Ratio Test. The complete calculations used for 1 (a) are shown in the Appendix. The tables used to determine the significance of the value of F can be found in appropriate textbooks.

The above calculations show that calcium additions are proven (with 95 percent certainty) to significantly affect only the impact properties of basic steel. Although the average values of the other properties for steel deoxidized with aluminum plus calcium generally are seen to be slightly higher than the average values for steels deoxidized with aluminum only, the difference has not been proven at a statistically significant level. The differences in the properties of the aluminum-killed and the aluminum plus calcium-killed steels may in reality actually exist, but with the number of samples taken in this investigation, there is insufficient evidence to prove that this is the case. Perhaps if more keel blocks had been cast and more tensile bars pulled, i.e., more samples taken, a statistically significant difference would have been seen to exist.

Therefore, except for the case of impact properties of basic steel, the beneficial effect of calcium additions must be said to be: Not Proven.

Conclusions

A statistical analysis of the ductility and impact properties of sand cast steels killed with aluminum only and with aluminum plus calcium yields the following conclusions:

1. Any beneficial effect of calcium on the elongation, reduction of area, and impact properties of the acid electric steel studied was not proven to exist.

2. Any beneficial effect of calcium on the elongation and reduction of area of the basic electric steel studied was not proven to exist.

3. Calcium had a beneficial effect on the impact properties of the basic electric steel studied.

APPENDIX

Variance Ratio Test Calculations for the Elongation of Sand Cast Acid Steel

Al only	Coded χ	χ^2	Al + CaSi	Coded χ	χ^2	Al + CaMnSi	Coded χ	χ^2	Al + Graphidox	Coded χ	χ^2
28%	5	25	32%	9	81	30%	7	49	28%	5	25
29%	6	36	33%	10	100	30%	7	49	26%	3	9
25%	2	4	27%	4	16	30%	7	49	31%	8	64
23%	0	0	30%	7	49	28%	5	25	85%	16	98
30%	7	49	27%	4	16	27%	4	16			
135%	20	114	149%	34	262	145%	30	188			
$\bar{X}$ = 27.0%			$\bar{X}$ = 29.8%			$\bar{X}$ = 29.0%			$\bar{X}$ = 28.3%		

APPENDIX—(Con't)

$\Sigma(\chi) = 100$

$\Sigma(\chi^2) = 662$

$N = 18$

Correction Factor $= \frac{(100)^2}{18} = 556$

Total Sum of Squares -
$662 - 556 = 106$, with 17 degrees of freedom

Between Sample Sum of Squares -

$$\frac{(20)^2}{5} + \frac{(34)^2}{5} + \frac{(30)^2}{5} + \frac{(16)^2}{3} - 556$$

or $80 + 231 + 180 + 85 - 556 = 20$, with 3 degrees of freedom

Within Sample Sum of Squares -
$106 - 20 = 86$, with 14 degrees of freedom

Variance between samples $= \frac{20}{3} = 6.67$, with 3 degrees of freedom

Variance within samples $= \frac{86}{14} = 6.15$, with 14 degrees of freedom

$$F = \frac{6.67}{6.15} = 1.08 \quad \frac{(3)}{(14)}$$

Reference to tables of F indicates that no significant difference exists between samples.

MAGNETIC PROPERTIES OF CAST CARBON STEELS

by

W. J. Jackson, M.Sc., A.R.I.C., A.I.M.

This report is a summary of The British Steel Castings Research Association's studies on the magnetic properties of cast steel. Part II of this report will appear in the next issue of the Journal of Steel Castings Research.

ABSTRACT

This investigation has been concerned with the measurement of the effect of heat treatment on the magnetic permeability of cast carbon steels with carbon contents in the range 0.10 to 0.34 percent.

The practical objective of this work was to discover whether a heat treatment could be devised which offered the possibility of economy in furnace time compared with full annealing without detriment to the magnetic permeability. It has been shown that if the cast steels are slowly cooled from 1380 to 1200 degrees F and then air cooled, the permeability is higher at both low and high field strengths than that for the same steels in the fully annealed condition.

The practical objective of the work has thus been secured, since in batch type heat treatment furnaces, this treatment is more economical in both time and heat than a full annealing treatment.

INTRODUCTION

Since the early days of electrical machinery, commercial alloys of iron and carbon have been used for core materials. Of the available data on magnetic properties of iron-carbon alloys, those provided by Yensen[1] in 1924 probably show most clearly that the effect of increasing carbon is to impair the magnetic properties of the alloy. Yensen's alloys were however, made from pure materials, and his results cannot be taken as representative of commercial alloys, whether in cast or wrought form. The magnetic properties of various ferrous materials were compared by Gumlich[2] in 1912, but published data on the magnetic properties of cast steel, one of the more widely used ferrous materials in present day use in electrical engineering, appear to be wholly lacking.

A brief review of the design and manufacturing techniques of high permeability steel castings has recently been made by Hinsley[3], in which it is pointed out that while reduction in carbon content of a steel increases the magnetic permeability, at the same time strength and hardness are impaired. Therefore, for applications where strength is essential, there is a limit to the extent that carbon can be lowered. In such cases, a compromise must be reached, and the effect of heat treatment becomes important.

The present work was conducted with two main objects in view. The first objective was to provide data on the magnetic and tensile properties of cast steel of varying carbon content, in different conditions of heat treatment, and the second objective was to determine the influence of different heat treatments on the magnetic properties of a given cast steel.

Part I—The Magnetic Properties of Cast Steel of Varying Carbon Content, in Different Conditions of Heat Treatment.

Provision of Test Material

Five 100-pound high frequency furnace heats were made from the same base charge, and carburized to the following nominal carbon contents: 0.10 percent, 0.15 percent, 0.20 percent, 0.25 percent, 0.30 percent.

Each of the five 100-pound heats was made from the same scrap charge of low carbon tube steel. Carburization was effected by pig iron. Similar additions of ferro-silicon and ferro-manganese were added to each heat, about one quarter of the ferro-silicon being added prior to the pig iron addition. A final addition of aluminum equivalent to 3 pounds per long ton was made prior to pouring, which in each case was carried out within the temperature range 2875 to 2910 degrees F. Throughout the series of heats, the final analyses, as shown in Table I, showed no appreciable variation and the total "residual alloy" content of nickel, chromium and molybdenum did not exceed 0.12 percent.

Four clover leaf test blocks were cast from each heat. One block from each heat was annealed (3 hours at 1740 F, furnace cooled), one block from each heat was normalized (3 hours at 1740 degrees F, air cooled), while the two remaining blocks were left in the as-cast condition.

One magnetic test ring was machined from a test block of each composition in each condition of heat treatment. The rings were removed from the lower halves of each test block, a slice approximately ¼ inch thick being first sawed from the bottom to clear any defects.

The test rings were not amenable to radiographic inspection, and to ensure soundness the density of each ring was determined prior to magnetic testing. Density results, given in Table II, indicated that the soundness of that portion of the test block from which each ring was removed was satisfactory. The mean hardness of each test ring was determined after the magnetic testing, and the hardness figures along with tensile strength are also recorded in Table II.

TABLE I—Results of Chemical Analyses of Carbon Steels Used in Part I

Heat Number	Composition, Percent							
	C	Si	Mn	S	P	Ni	Cr	Mo
1	0.10	0.33	0.67	0.029	0.041	0.03	0.03	0.01
2	0.14	0.39	0.60	0.029	0.041	0.09	0.02	0.003
3	0.19	0.30	0.48	0.029	0.039	0.06	0.03	0.02
4	0.24	0.28	0.41	0.031	0.040	0.02	0.05	0.02
5	0.34	0.44	0.55	0.031	0.041	0.02	0.03	0.01

TABLE II—Density, Hardness and Tensile Strength Values of Magnetic Test Rings

Heat No.	Carbon Content	Condition	Density of ring (gm./c.c)	Mean Vickers Diamond Hardness of ring (load 20 kg.)	Tensile Strength psi
1	0.10%	Annealed	7.835	120	57,800
		Normalized	7.831	128	61.500
		As-cast	7.829	123	.....
2	0.14%	Annealed	7.818	133	63,000
		Normalized	7.827	140	67,100
		As-cast	7.827	140	.....
3	0.19%	Annealed	7.831	135	64,500
		Normalized	7.835	140	69,400
		As-cast	7.835	138	.....
4	0.24%	Annealed	7.829	145	71,000
		Normalized	7.827	156	75,600
		As-cast	7.830	155	.....
5	0.34%	Annealed	7.821	177	80,900
		Normalized	7.819	180	87,800
		As-cast	7.820	180	.....

TABLE III—Magnetization and Permeability Values for Carbon Steels Tested in the Annealed Condition

Flux Density B (Gauss)	0.10% Carbon Steel (Heat No. 1) H (Oersted)	μ	0.14% Carbon Steel (Heat No. 2) H (Oersted)	μ	0.19% Carbon Steel (Heat No. 3) H (Oersted)	μ	0.24% Carbon Steel (Heat No. 4) H (Oersted)	μ	0.34% Carbon Steel (Heat No. 5) H (Oersted)	μ
5,000	2.1	2380	2.3	2173	2.4	2083	3.0	1666	4.2	1190
10,000	4.9	2040	5.5	1818	6.2	1612	7.8	1282	10.0	1000
14,000	14.7	952	17.0	824	19.5	718	24.0	583	29.7	471
15,000	21.5	698	26.3	570	28.5	526	35.0	429	44.0	341
16,000	43.0	372	43.0	372	51.0	314	59.0	271	71.0	225
17,000	81.0	209	82.0	207	85.0	200	98.0	173	128.0	133
18,000	144.0	121	142.0	127	154.0	117	165.0	109	203.0	88.7
19,000	235.0	81	230.0	83	....	....	270.0	70	....	....

TABLE IV—Magnetization and Permeability Values for Carbon Steels Tested in the Normalized Condition

Flux Density B (Gauss)	0.10% Carbon Steel (Heat No. 1) H (Oersted)	μ	0.14% Carbon Steel (Heat No. 2) H (Oersted)	μ	0.19% Carbon Steel (Heat No. 3) H (Oersted)	μ	0.24% Carbon Steel (Heat No. 4) H (Oersted)	μ	0.34% Carbon Steel (Heat No. 5) H (Oersted)	μ
5,000	2.6	1923	3.3	1515	3.4	1470	4.1	1219	5.3	943
10,000	6.6	1515	7.2	1388	8.1	1234	9.7	1031	12.3	831
14,000	17.0	823	21.3	657	21.5	651	27.0	519	35.5	394
15,000	24.3	617	33.0	454	35.0	428	41.0	366	50.0	300
16,000	43.0	372	54.0	296	57.0	281	62.0	258	75.0	213
17,000	70.6	241	93.0	183	90.0	189	99.0	172	111.0	153
18,000	130.0	138	143.0	126	153.0	118	160.0	113	183.0	98
19,000	209.0	91	250.0	76	245.0	76	260.0	73	....	....

TABLE V—Magnetization and Permeability Values for Carbon Steels Tested in the As-Cast Condition

Flux Density B (Gauss)	0.10% Carbon Steel (Heat No. 1) H (Oersted)	μ	0.14% Carbon Steel (Heat No. 2) H (Oersted)	μ	0.19% Carbon Steel (Heat No. 3) H (Oersted)	μ	0.24% Carbon Steel (Heat No. 4) H (Oersted)	μ	0.34% Carbon Steel (Heat No. 5) H (Oersted)	μ
5,000	2.4	2083	2.8	1785	2.9	1724	4.4	1136	6.0	833
10,000	6.2	1613	7.5	1333	8.3	1205	11.1	901	14.9	671
14,000	17.5	800	23.2	603	24.3	576	39.5	354	43.0	326
15,000	27.0	556	37.0	405	40.0	375	59.0	254	59.0	254
16,000	47.0	340	59.0	271	63.0	253	90.0	178	83.0	193
17,000	81.0	210	99.0	172	103.0	165	165.0	103	129.0	132
18,000	137.0	131	160.0	113	165.0	109	....	....	203.0	89
19,000	210.0	90	255.0	75	....	....	....	....	....	....

Test Results

The magnetization curve for each material was determined. The results of the tests are given in Tables III, IV and V, and typical magnetization curves are shown in Figure 1.

The hysteresis loop for each material was also determined, up to a maximum field strength of 250 oresteds. These results are given in Table VI, only one branch of the loop being recorded, since with such material the other branch can be determined by symmetry. Values of remanence (B_r) and coercive force (H_c) determined from the hysteresis loops are given in the same table.

Discussion

The results given in Tables III, IV and V, show that irrespective of carbon content, a superior permeability is associated with steels in the annealed condition. A convenient method of summarizing these results diagrammatically is to plot permeability (μ) against flux density (B), as shown in Figure 2. It is then immediately apparent that permeability decreases with increasing carbon content for this steel in each of the three conditions of heat treatment. Furthermore, while an annealed structure exhibits a superior maximum permeability value for each of the carbon contents examined, the next structure in order of superiority depends on the carbon content, for the 0.10, 0.14 and 0.19 percent carbon as-cast structures have a higher maximum permeability than the normalized, while the 0.24 and 0.34 percent carbon as-cast structures are inferior.

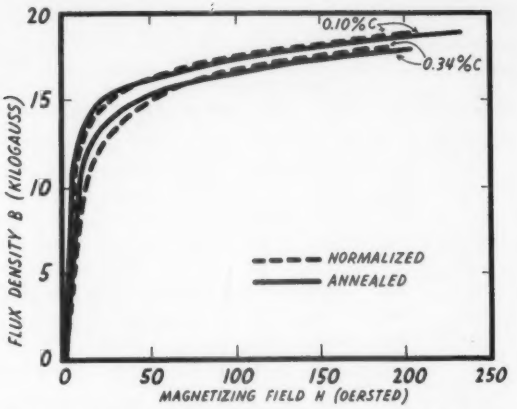

Figure 1—Magnetization curves for 0.10 percent and 0.34 percent carbon steels in the annealed and normalized conditions.

From the magnetic hysteresis data given in Table VI, it is apparent that the remanence of the annealed material is substantially similar to that of the normalized material, but the annealed material exhibits a lower coercive force in each case. It is interesting to note that if maximum permeability (determined from the data in Table VI) is plotted against the reciprocal of the coercive force, as in Figure 3, the points fall very nearly on the straight line passing through the origin, demonstrating that maximum permeability is approximately inversely proportional to coercive force.

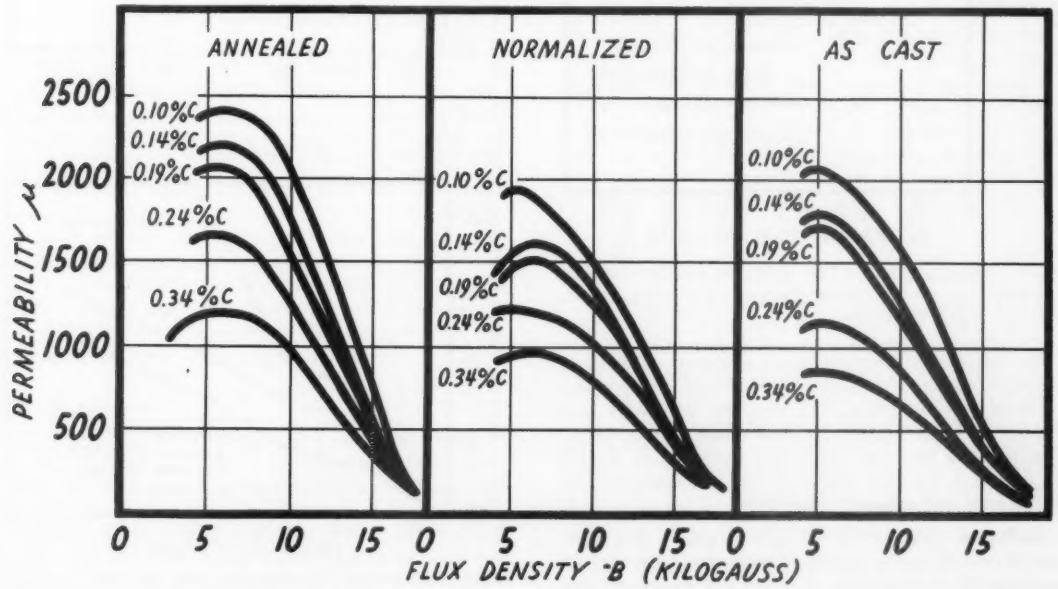

Figure 2—Permeability versus flux density for a range of carbon steels, in the annealed, normalized, and as-cast conditions.

TABLE VI—Hysteresis Loop Data

Field H (Oersted)	FLUX DENSITY, B (Gauss)														
	Annealed Material					Normalized Material					As-Cast Material				
	0.10%C (1)	0.14%C (2)	0.19%C (3)	0.24%C (4)	0.34%C (5)	0.10%C (1)	0.14%C (2)	0.19%C (3)	0.24%C (4)	0.34%C (5)	0.10%C (1)	0.14%C (2)	0.19%C (3)	0.24%C (4)	0.34%C (5)
+250	+19200	+19150	+18750	+18850	+18450	+19600	+19000	+19100	+18950	+18650	+19450	+18800	+18900	+17700	+18650
+40	+16200	+15900	+16000	+15600	+15200	+16300	+15800	+16000	+15500	+15200	+16200	+15600	+15500	+14600	+15000
+10	+14600	+14300	+13900	+13800	+13600	+14100	+14000	+13700	+13400	+13100	+13900	+13300	+13500	+12400	+12000
−0.5	+ 7100	+ 8000	+ 6900	+ 8600	+10000	+ 7300	+ 8300	+ 7700	+ 9300	+10200	+ 5700	+ 5900	+ 6500	+ 7500	+ 8200
−1.0	+ 5300	+ 5900	+ 5200	+ 7100	+ 9200	+ 6500	+ 7400	+ 6500	+ 8500	+ 9700	+ 3700	+ 4500	+ 5000	+ 6700	+ 7800
−2.0	− 4200	− 1500	− 100	+ 2300	+ 6000	+ 1300	+ 4000	+ 3000	+ 6000	+ 8100	− 2000	− 1000	+ 300	+ 3800	+ 6100
−4.0	− 8000	− 7500	− 5900	− 4100	− 1000	− 7000	− 4200	− 1500	− 1900	+ 3800	− 7300	− 5900	− 5400	− 2300	− 2100
−10.0	− 9800	−12300	−10100	−10700	− 8900	−12000	−10600	−10300	− 9500	− 7700	−11500	−10900	−10200	− 9000	− 6800
−40	−15600	−15700	−15500	−15100	−14500	−16000	−15500	−14000	−14900	−14200	−15700	−15200	−14900	−14000	−13800
*Remanence B_r	8030	9045	8700	9700	10500	8470	8960	8975	9900	10500	6610	7300	7300	8000	8450
*Coercive Force H_c	1.7	1.7	1.95	2.3	3.7	2.1	2.6	2.7	3.4	5.5	1.6	1.8	2.1	3.0	5.2

*Determined from above data. (i.e., H=250 oersteds max.)

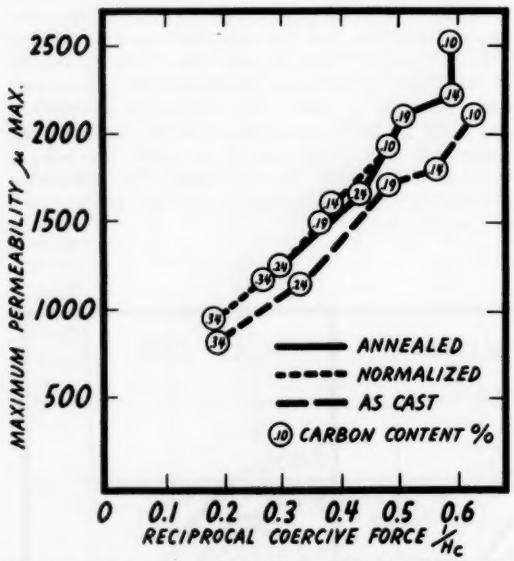

Figure 3—Maximum permeability versus the reciprocal of coercive force for a range of carbon steels, in the annealed, normalized, and as-cast conditions.

To relate tensile properties to magnetic properties, ultimate tensile stress has been plotted against the value of field strength (H) required to give a flux density of 15,000 gauss, an arbitrarily chosen value. The relation between these two variables is shown in Figure 4, for the series of carbon steels in the normalized and annealed conditions.

In Figure 5, the field strength to give a flux density of 15,000 gauss has been plotted against carbon content. This illustrates that for the order of flux densities at which electrical equipment normally

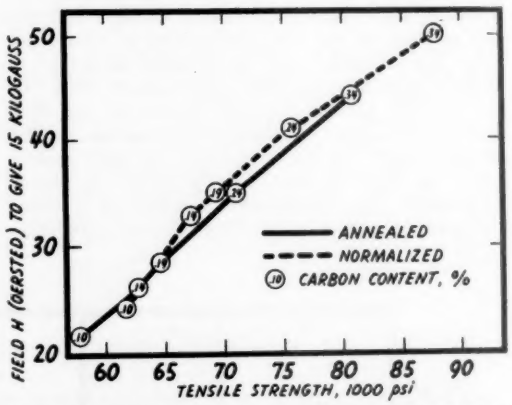

Figure 4—Variation of magnetizing field necessary to give a flux density of 15,000 gauss with ultimate tensile strength for a series of carbon steels, in the annealed and normalized conditions.

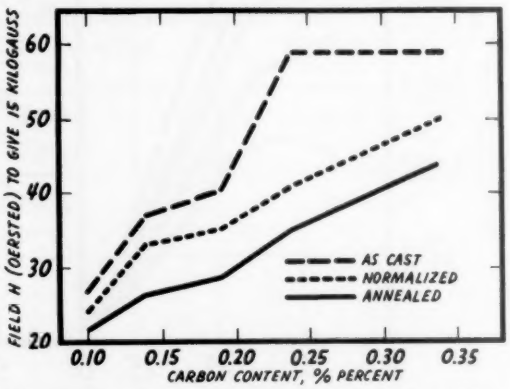

Figure 5—Variation of magnetizing field necessary to give a flux density of 15,000 gauss with carbon content for a series of carbon steels, in the annealed, normalized, and as-cast conditions.

operates, magnetic properties of the as-cast material are inferior to the normalized, despite the fact that the 0.10, 0.14 and 0.19 percent carbon as-cast steels develop a higher maximum permeability than the normalized steels.

References

1. Yensen, T. D., "Magnetic Properties of the Ternary Alloys Fe-Si-C.," Trans. American Inst. Elec. Eng., 1924, 43, pp. 145 - 175.
2. Gumlich, E., "Magnetic Properties of Iron-Carbon and Iron-Silicon Alloys," Trans. Faraday Soc., 1912, 8, pp. 98 - 114.
3. Hinsley, J. F., "High Permeability Steel Castings," Electrical Rev., 1955, February 11.

ABSTRACTS OF FUNDAMENTAL PAPERS ON STEEL CASTING RESEARCH

Based on a review of the current literature on technical research subjects. (Copies of these articles available from original publishers only.)

Cleaning and Finishing

"New Milling Process Trims Complex Shapes," STEEL, April 4, 1960. Fifty production steel forgings, used on North American Aviation Inc.'s A3J jet airplane, are being electrochemically milled to remove decarburized surfaces. The process, developed by the company's engineers is the latest in line of electromachining techniques. Submitting the high strength steel parts to electrolytic attack in an acid solution, the engineers can also accomplish over-all metal removal for weight reduction, selectively machine specified surfaces, and refine the tolerances of the part. With further development, the process is expected to be widely used.

Vacuum Treating

Vishkarev, A. F., and Kondakov, V. V., "Decomposition of Nonmetallic Inclusions in (Liquid) Steel During Vacuum Treatment," PROIZVODSTVO OBRABOTKA STALI SPLAVOV, Collection of Papers, #38; Metallurgizdat, 1958, pp. 196-208. Henry Brutcher, Technical Translation, No. 4598, P. O. Box 157, Altadena, California. Study of extent and rate of decomposition of nonmetallic inclusions in liquid steel under vacuum. Reaction by which nonmetallic inclusions are decomposed. Autocatalytic character of their decomposition. Variation of pressure in system during decomposition. Numerical data on decrease of amount of inclusions of the MnO, $MnO \cdot FeO$, $Cr_2O_3 \cdot FeO$, silicate, and aluminate types. Relationship between extent of decomposition of inclusions and their thermodynamic stability.

Metallography

Chalfant, G. M., "Revealing Lead Inclusions in Leaded Steels," METAL PROGRESS, September 1960. A new metallographic procedure permits direct microscopic observation and identification of lead inclusions in leaded carbon, alloy and resulfurized steels. The method includes final polishing with an aqueous suspension of gamma alumina that is precisely neutral.

Non-Destructive Testing

Posakony, Gerald J., and Loetz, Merle R., "Investigation of Methods for Determining Actual Flaw Size in Materials by Non-Destructive Ultrasonic Techniques," WADC Technical Report 59-302, December, 1959. By electronic networks, ultrasonic reflections are displayed into a three dimensional view of the internal structure of a flat metal part. Three dimensional pictures are included to show the resultant of the single and multiple transducer techniques. Various frequencies and materials are evaluated to establish preliminary applicability of the processes.

Testing

Westbrook, J. H., "An Improved Microhardness Tester for High-Temperature Use," ASTM BULLETIN, May, 1960. The design, construction, and operation of an improved high-temperature microhardness tester are described. Testing is done *in vacuo;* other specifications include: temperature range,—190 to 1500 C; load range, 5 to 1000 g; rate of loading, 0.2 to 1.2 mm per min; time of indentation, 2 to 60 sec. Examples of various applications of the instrument are given to demonstrate its capabilities and the variety of problems for which it may be used.

Deoxidation

Fischer, W. A., and Wahlster, M., "Studies of Formation of Nonmetallic Inclusions in the Deoxidation of Steel with Silicon," ARCHIV EISENH, Vol. 29, 1958, Henry Brutcher, Technical Translation No. 4416, P. O. Box 157, Altadena, California. Microchemical and metallographic studies of samples withdrawn from molten iron saturated with atmospheric oxygen, at various temperatures, and held in crucibles of silica, lime, magnesia, and alumina, before and after deoxidation with silicon. Formation of silicate inclusions after addition of silicon for deoxidation and the changes these inclusions undergo during reoxidation. Electrochemical isolation of unsaturated and saturated silicate inclusions.

Hot Tearing

Efimov, V. A., et al, STAL, Vol. 15, No. 7, 1955, pp. 601-606. Henry Brutcher, Technical Translations, No. 3644, P. O. Box 157, Altadena, California. Investigation of shrinkage and plastic properties of various low, medium and high carbon killed steels, some of them with low alloy additions, in relation to their propensity to develop hot tears in the ingot stage. Formula for calculating the force leading to rupture of ingot skin. Numerical data on longitudinal and transverse shrinkage during pouring and solidification of 6.6 ton ingots of several different steels. Time required by ingots to shrink away from mold wall at the various levels. Relationship between tearing of ingots and semiproducts, and extent of shrinkage during solidification.

Solidification

Neimark, V. E., et al, "Influence of Titanium and Combined Additions of Boron, Vanadium, and Titanium upon the Crystallization of Steel," STAL, Vol. 8, No. 3, 1948, pp. 248-254. Henry Brutcher, Technical Translations, No. 2238, P. O. Box 157, Altadena, California. Experimental study of effect of small additions of titanium and combined additions of boron and vanadium and titanium upon primary crystallization, kinetics of isothermal decomposition of austenite, and hardenability of carbon steel. Results of micrographic analysis of as-cast steel; study of austenite grain from primary crystallization and of ferrite precipitation. Effect on primary crystal structure, kinetics of isothermal decomposition of austenite, and on hardenability as function of temperature range.

Design

Manson, S. S., "Cumulative Fatigue Damage," MACHINE DESIGN, August 18, 1960. Cumulative damage in fatigue is complicated by introduction of nonrepetitive loading history. Thus, generalized procedures cannot be provided to rigorously indicate the mechanism of the process and at the same time be sufficiently simple to apply for engineering purposes. This article will emphasize the applicability aspect. But, the relations provided are as consistent as possible with the present state of knowledge on fatigue and material behavior under complex loading conditions.

Sand Testing

Kitago, S., and Kozaki, F., "The Measurement of Relative Density of Sand," ASTM Bulletin, September 1960. The existing standard methods of measuring maximum or minimum density of soils to establish their relative densities are not adequate for sandy or granular soils. In this paper, a proposal for a procedure to obtain maximum and minimum densities is presented, derived from the Bureau of Reclamation method, but more practical and easier to handle, because it eliminates the need for specially prepared apparatus and highly skilled operators.

Testing

Poteat, L. E., and Jones, R. W., "Circular-Patch for Evaluating Armor Crack Susceptibility," WELDING RESEARCH SUPPLEMENT, August 1960. An investigation was conducted to determine the effect of different procedures on the effectiveness of the circular-patch test specimen in the evaluation of plate crack susceptibility and to determine conditions suitable for a standard test. A test procedure was selected and used on several different heats of armor steel. Evaluation of these heats by this procedure placed the heats in the correct order of crack susceptibility as determined from the known fabrication history of the heats.

Properties

Leslie, W. C., Rickett, R. L., and Lafferty, W. D., "Effect of Heat Treatment in the Ferrite-Austenite Region on Notch Toughness of Low-Carbon Steels," Transactions of the Metallurgical Society of AIME, Vol. 218, August 1960. Notch toughness of 0.10 percent C steels, rimmed or killed, is improved by holding the steel at a temperature just above the A_1, followed by air cooling. The improvement can be gained without apparent change in gross microstructure or hardness. The limits of the process have been determined and some possible reasons for the observed effects are discussed. The results appear to indicate that the current theories of transition temperature are inadequate.

Sand Research

Vingas, G. J., and Zrimsek, A. H., "Sand Angularity and Shape Factors," MODERN CASTINGS, October 1960. The purpose of this paper is to show the limitation of the surface area to volume measures in describing shapes, interpreting sharp corners, edges or surfaces or designating numerically shapes as they depart from the spherical. The air permeability method is discussed, with its limitations and abilities in measuring surface area as such and how it compares with other methods. The microscope still remains the only tool capable of assigning a relative shape.

Hydrogen Embrittlement

Steigerwald, E. A., Schaller, F. W., and Trojano, A. R., "The Role of Stress in Hydrogen Induced Delayed Failure," Transactions of the Metallurgical Society of AIME, Vol. 218, October 1960. The initiation of localized cracking in hydrogenated high strength steel was dependent on the development of a critical hydrogen concentration and relatively insensitive to the magnitude of the applied stress. The stress was believed to influence the delayed failure process by providing the means for grouping the hydrogen. On the basis of an assumed distribution law the observed changes in the lower critical stress as a function of notch acuity, yield strength, and temperature were predictable over a significant range of these variables.